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OPTIMAL DG PLACEMENT BASED ON STATIC SECURITY ASSESSMENT

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ABSTRACT:

The integration of distributed generation (DG) in distribution network may significantly affect its performance. Transmission networks are no longer accountable solely for voltage security issues in distribution networks with penetration of DGs. The reactive power support from the DG sources greatly varies with the type of DG units and may potentially distress the larger portion of the network from the voltage stability aspects. This paper presents the analysis for the selection of the best type of DG unit among different categories and its optimal location that can enhance the static security of distribution network with simultaneous improvement in voltage profile.

Key words: Static Security Analysis (SSA), Static Security Index (SSI), DG, PF, Fast Approach, Line over Load Index (LOI) & Real Power Loss Reduction.

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1. INTRODUCTION

The integration of DG is expected to play an increasingly important role in the electric power system infrastructure planning and market operations. The integration of DG at the distribution network results in operating situations that do not occur in a conventional system without generation directly connected at the distribution level. Attention must be paid to effectively eliminate the potentially adverse impacts that DG penetration could impress on the electric delivery system. Inappropriate DG placement and sizing may increase system losses and network capital and operating costs. Hence, systematic studies and planning are required to locate and operate the DGs at the distribution level in order to improve voltage profile, to reduce system losses, and to enhance the stability. Power systems are expected to become more heavily loaded in the forthcoming years as the demand for electric power rises sharply. The economic and environmental concerns limit the construction of new transmission and generation capacity.

This may result in deficit of local reactive power support in heavily loaded system which in turn causes the progressive voltage decline. The decline in voltage level is one of important factors which restrict the increase of load served by distribution companies. Therefore, it is necessary to consider Static Security constraints for planning and operation of distribution systems.

As the main form of decentralized power supply, the proportion of the Distributed generation (DG) in the distribution network will be increasingly larger. The access of the DG will change the original flow distribution, the transmission line power, etc, which will be a great impact to the static stability of distribution network. Therefore, the static stability indicators and stability analysis are the premise and basis of measures to improve stability.

DG has many advantages over centralized power generation, including reduction of power system losses and improved voltage profile. The optimum DG placement and sizing at planning stage of distribution system is necessary to achieve the maximum benefits. The non-optimum DG placement and sizing could results in increase power losses and affect the system voltage profile. However the optimum

A method for DG placement in radial distribution network based on Voltage security margin (VSM) enhancement and loss reduction is presented in [15], which use CPF to identify the most sensitive bus to voltage collapse. The work in [16] is suggested that voltage magnitude is not a suitable indicator for the proximity to voltage collapse. A method is presented for locating and sizing of DGs to enhance voltage stability and to reduce network losses simultaneously in [18], where Modal analysis and continuous power flow are used for DG placement in the event of reactive power deficit. The enhancement of voltage profile, load ability with simultaneous reduction distribution losses considering voltage related constraint is discussed in [19]. Based on the literature review discussed above, it has been observed that the different issues in the field of distributed generation are covered which are based on optimal location and sizing of DG, loss minimization, voltage stability enhancement and reconfiguration of distribution network after the integration of DG resources. This paper is mainly focused on static security analysis which has been rarely addressed earlier in the literature. Section 1 gives the Introduction about the work and rest of the paper is organized as follows: Section 2 presents SSA. Proposed analytical expressions for finding optimal sizes of various DG types are introduced in Section 3 & 4. Optimal placement and operating power factor of DG is also addressed in the section. Section 5 presents numerical results of application of

developed analytical expression in two different test systems, interesting observations along with discussions. Finally, the major contributions and conclusions are summarized in Section 6.

2. STATIC SECURITY ANALYSIS (SSA)

A given system operating condition is said to be static secure, if the bus voltage magnitudes and real power generation of generator buses are well within their limits, without any occurrence of line overloads. In this paper, we define a term called *Static Security Index (SSI)* for evaluating static security level for a given system operating condition and a specified contingency. The SSI is defined by calculating the Line Overload Index (LOI) and Voltage Deviation Index (VDI) as given by (1) and (2) respectively.

$$LOI_{km} = \begin{cases} \dfrac{S_{km} - MVA_{km}}{S_{km}} \times 100 & if\ S_{km} > MVA_{km} \\ 0 & if\ S_{km} \le MVA_{km} \end{cases} \quad (1)$$

$$VDI_k = \begin{cases} \dfrac{|V_k^{\min}| - |V_k|}{|V_k^{\min}|} \times 100 & if\ |V_k| < |V_k^{\min}| \\ 0 & if\ |V_k^{\min}| \le |V_k| \le |V_k^{\max}| \\ \dfrac{|V_k| - |V_k^{\max}|}{|V_k^{\max}|} \times 100 & if\ |V_k| > |V_k^{\max}| \end{cases} \quad (2)$$

$$SSI = \frac{W_1 \sum_{i=1}^{N_L} LOI_i + W_2 \sum_{i=1}^{N_B} VDI_i}{N_L + N_B} \quad (3)$$

where S_{km} and MVA_{km} represents the Mega Volt-Ampere(MVA) flow and MVA limit of branch k-m, $|V_{k\min}|$, $|V_{k\max}|$ and $|V_k|$ the minimum voltage limit, maximum voltage limit and bus voltage magnitude of k^{th} bus respectively, N_L and N_B being number of lines and buses respectively.

Evaluating the Static Security Index (SSI) as given by (3), each pattern is labeled as belonging to one of the four classes as shown in Table I. In calculation of SSI, weighting factors for LOI and VDI are taken as $W1=3$ and $W2=2$ respectively. These weighting factors are fixed based on the order of priority in requirement of system security. SSI is a percentage measure, taking value in the range of 0 to 100.

Here in this paper, SSA is done by varying the system load 100% to 200% of their base case values and SSI is found. The work can also be extended by considering the outages of lines in the network. Hence, this work gives an overview of effect of DG on improvement of Static Security of the system by considering only the variation of the load in the system. Also, this work can be extended for SSA of a system by considering line outages and generator outages.

Table I Security Levels

Static Security Index	Security Status
SSI=0	Secure
0<SSI≤5	Critically Secure
5<SSI≤15	Insecure
SSI>15	Highly Secure

3. POWER LOSS CALCULATION

The real power loss in a system is given by (1). This is popularly referred to as "exact loss" formula [11]. The losses can also be calculated by using any conventional load flow techniques. Moreover, in this paper, the backward/forward sweep method is utilized to perform the power flow in the distribution network.

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}[\alpha_{ij}(P_iP_j + Q_iQ_j) + \beta_{ij}(Q_iP_j - P_iQ_j)] \tag{1}$$

Where

$$\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos(\delta_i - \delta_j)$$

$$\beta_{ij} = \frac{r_{ij}}{V_iV_j}\sin(\delta_i - \delta_j)$$

P_i and Q_i are active and reactive power at bus i.

The above equation is used in power loss calculation in the proposed work which is also the exact loss formula.

4. PROPOSED ALGORITHM

The purpose of this paper is to find the best location and size of a DG unit in order to decrease the power losses of the system and improve the voltage profile through static security analysis. The proposed algorithm of this paper gives the most optimum location and size of a DG unit in a distribution system based on a Static Security Index (SSI) which considers the voltage deviation at nodes and Line overloads.

4.1. To find Location of DG Placement

The location of DG is chosen as the one that improves the SSI. This could be done by injecting the DG at each node calculating the SSI by using equation. (2). The best location is selected as the node with least SSI.

4.2. To find Optimal Power Factor [14]

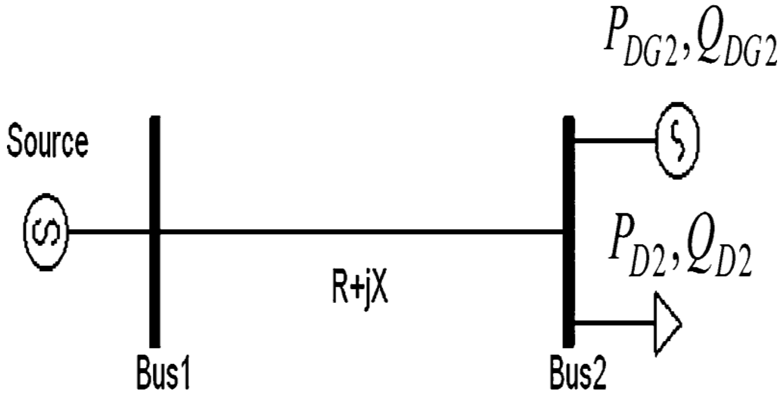

Figure 1. Two bus distribution system

Consider a simple distribution system with two buses, a source, a load and DG connected through a transmission line as shown in Fig. 1. The power factor of the single load (PF_{D2}) is given by (4)

$$PF_{D_2} = \frac{P_{D2}}{\sqrt{P^2_{D2} + Q^2_{D2}}} \quad (4)$$

It can be proved that at the minimum loss occur when power factor of DG is equal to the power factor of load as given by (5).

$$PF_{D_2} = PF_{DG_2} = \frac{P_{DG_2}}{\sqrt{P^2_{DG_2} + Q^2_{DG_2}}} \quad (5)$$

In practice, a complex distribution system includes a few sources, many buses, many lines and loads. The power factors of loads are different. If each load is supplied by each local DG, at which the power factor of each DG is equal to that of each load, there is no current in the lines. The total line power loss is zero. The transmission lines are also unnecessary. However, that is unrealistic since the capital investment cost for DG is too high. Therefore, the number of installed DGs should be limited. To find the optimal power factor of DG for a radial complex distribution system, fast and repeated methods are proposed. It is interesting to note that in all the three test systems the optimal power factor of DG (Type 3) placed for loss reduction found to be closer to the power factor of combined load of respective system.

1) Fast Approach: Power factor of combined total load of the system (PFD) can be expressed by (5). In this condition, the total active and reactive power of the load demand are expressed as The “possible minimum” total loss can be achieved if the power factor of DG (PFDG) is quickly selected to be equal to that of the total load (PFD). That can be expressed by (6)

$$PF_{DG} = PF_D \quad (6)$$

2) Repeated Approach: In this method, the optimal power factor is found by calculating power factors of DG (change in a small step of 0.01) near to the power factor of combined load. The sizes and locations of DG at various power factors with respect to losses are identified from (5). The losses are compared together. The optimal power factor of DG for which the total loss is at minimum is determined. The present work uses the Fast Approach to find the optimal value of Power Factor of DG.

4.3. Computational Procedure for DG Placement and Sizing

- Read system data.
- Run the base case load flow.
- Compute SSI for base case.
- Calculate the optimal power factor of DG by using Fast Approach.
- Compute the SSI at each node using equation (3) by penetrating the DG at respective node
- Select the bus with least value of index and that is the optimal location of DG.
- Repeat the above steps for another penetration level of DG (if required).

5. RESULTS AND ANALYSIS

A) Case Study 1

The developed methodology is applied to 25kV, IEEE six bus system [12] shown in Figure 2 without any capacity and location constraint.

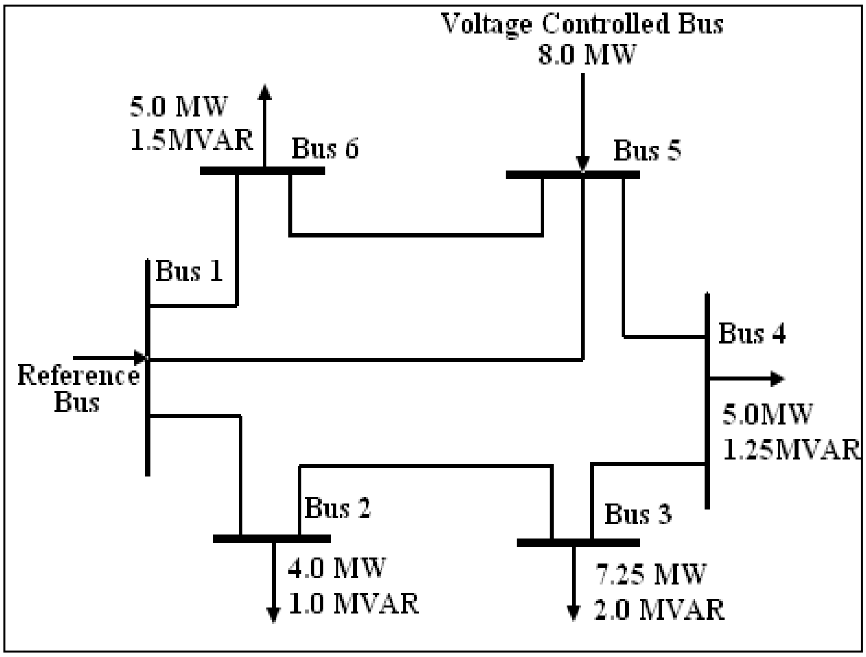

Figure. 2 Standard IEEE 6 bus test system

Table I shows the summary of the results of the proposed algorithm for IEEE 6 bus test system. The optimal location of DG has been found by SSI shown in Table II. The least value of the index is at bus no 3 for both 10% and 50% DG penetration levels and hence it is chosen as the best location and optimal size of DG is chosen by finding the optimal power factor of the DG using the proposed two approaches. From Figure 3 and Figure 4 it is evident that the DG placement through the proposed method improves the voltage profile and percentage power loss reduction at two different DG penetration levels.

Table I Summary of Results 6 Bus Test System

		6 BUS TEST SYSTEM	
DG PENETRATION LEVEL		10%	50%
OPTIMAL LOCATION (BUS NO)		3	3
OPTIMAL POWER FACTOR		0.96	0.96
OPTIMAL DG SIZE	PDG IN MW	2.25	11.35
	QDG IN MVAR	0.605	3.025
REAL LOSS BEFORE DG PLACEMENT in MW		0.7033	0.7033
REAL LOSS AFTER DG PLACEMENT in MW		0.4879	0.184
SSI before DG placement		11.348	11.348
SSI After DG placement		0.988	0.046
% REAL LOSS REDUCTION		30.627	73.837

Table II. SSI of Standard 6 Bus Test System for various locations of DG

DG Location	10% DG penetration		50% DG penetration	
	SSI	Status	SSI	Status
1				
2	3.78	Critically Secure	3.345	Critically Secure
3	**0.0988**	**Secure**	**0.046**	**Secure**
4	5.578	Insecure	4.787	Critically Secure
5	6.123	Insecure	5.879	Insecure
6	8.456	Insecure	7.456	Insecure

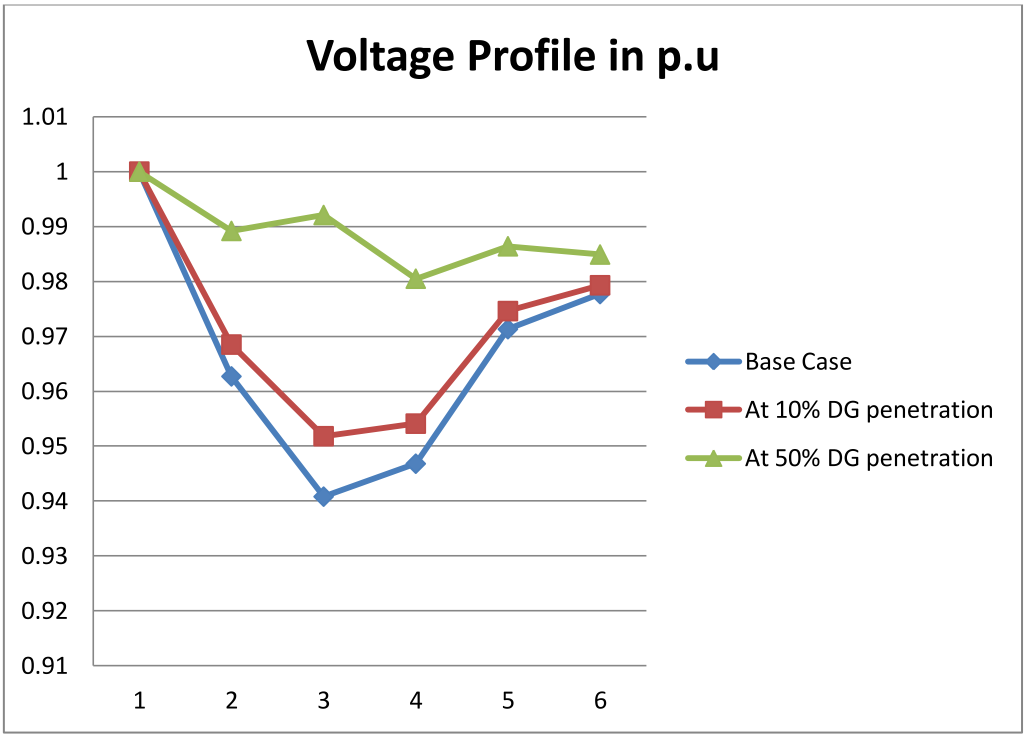

Figure 3 Voltage profile of Standard 6 bus Test System

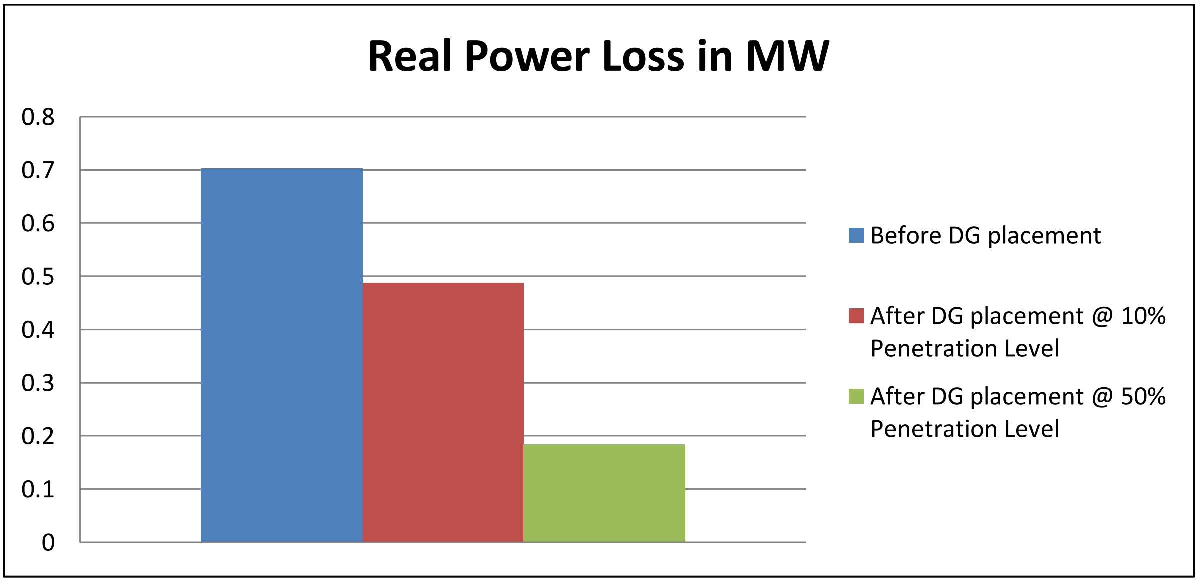

Figure 4 Real Power Loss profile of Standard 6 bus Test System

B) Case Study 2:

The algorithm has been applied to a radial system of sixteen buses with three feeders and three tie switches as shown in Figure 5. The line data is taken from [13] without any DG injection. The branches S15, S21and S26 are the tie branches.

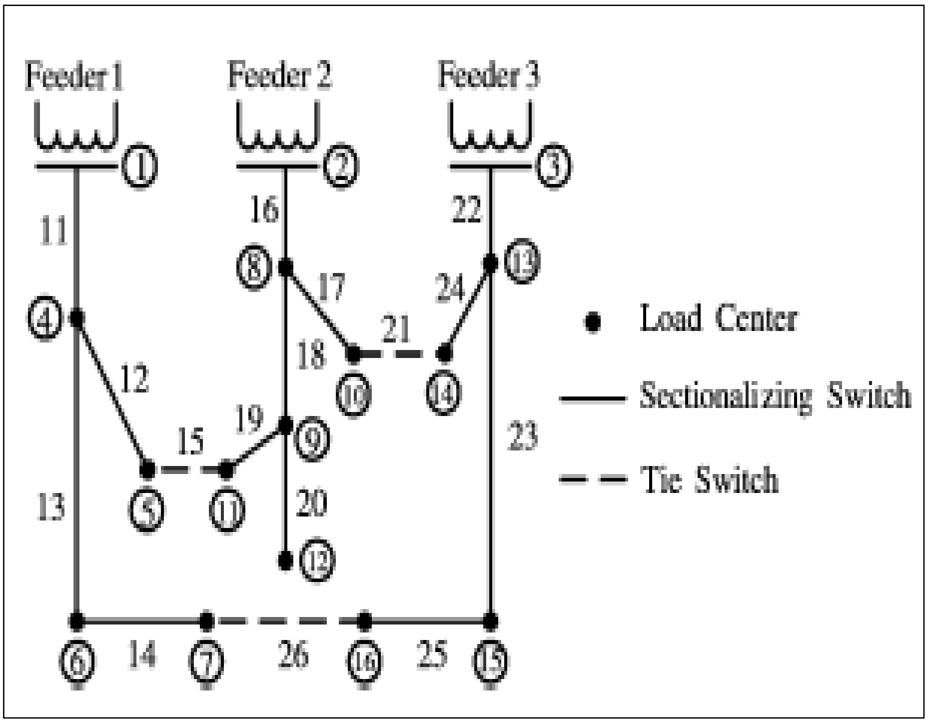

Figure 5 Standard Civanlar 16 bus test system

Table III Summary of Results 16 Bus Test System

		16 BUS TEST SYSTEM	
DG PENETRATION LEVEL		10%	50%
OPTIMAL LOCATION (BUS NO)		12	8
OPTIMAL POWER FACTOR		0.856	0.856
OPTIMAL DG SIZE	PDG IN MW	2.87	14.35
	QDG IN MVAR	1.73	8.65
REAL LOSS BEFORE DG PLACEMENT in MW		0.5036	0.5036
REAL LOSS AFTER DG PLACEMENT in MW		0.336	0.209
SSI before DG placement		13.676	13.676
SSI after DG placement		0.098	0.0348
% REAL LOSS REDUCTION		33.280	58.498

Table IV SSI of Standard 16 Bus Test System for various locations of DG

DG Location	10% DG penetration		50% DG penetration	
	SSI	Status	SSI	Status
1				
2				
3				
4	9.4678	Insecure	8.1211	Insecure
5	9.23	Insecure	7.8833	Insecure
6	9.76	Insecure	8.4133	Insecure
7	4.37	Critically Secure	3.0233	Critically Secure
8	5.123	Insecure	0.0348	Secure
9	5.578	Insecure	4.2313	Critically Secure
10	8.123	Insecure	6.7763	Insecure
11	9.456	Insecure	8.1093	Insecure
12	0.0984	Secure	3.7763	Critically Secure
13	6.345	Insecure	4.9983	Critically Secure
14	6.456	Insecure	5.1093	Insecure
15	5.6578	Insecure	4.3111	Critically Secure
16	4.3789	Critically Secure	3.0322	Critically Secure

Table III shows the summary of the results of the proposed algorithm for standard 16 bus test system. The optimal location of DG has been found by voltage indices shown in Table IV. The least value of the index is at bus no 12 and bus 2 respectively for 10% and 50% DG penetration levels and hence they are chosen as the best location and optimal size of DG is chosen by finding the optimal power factor of the DG using the proposed two approaches. From Figure 6 and Figure 7 it is evident that the DG placement through the proposed method improves the voltage profile and percentage power loss reduction at two different DG penetration levels.

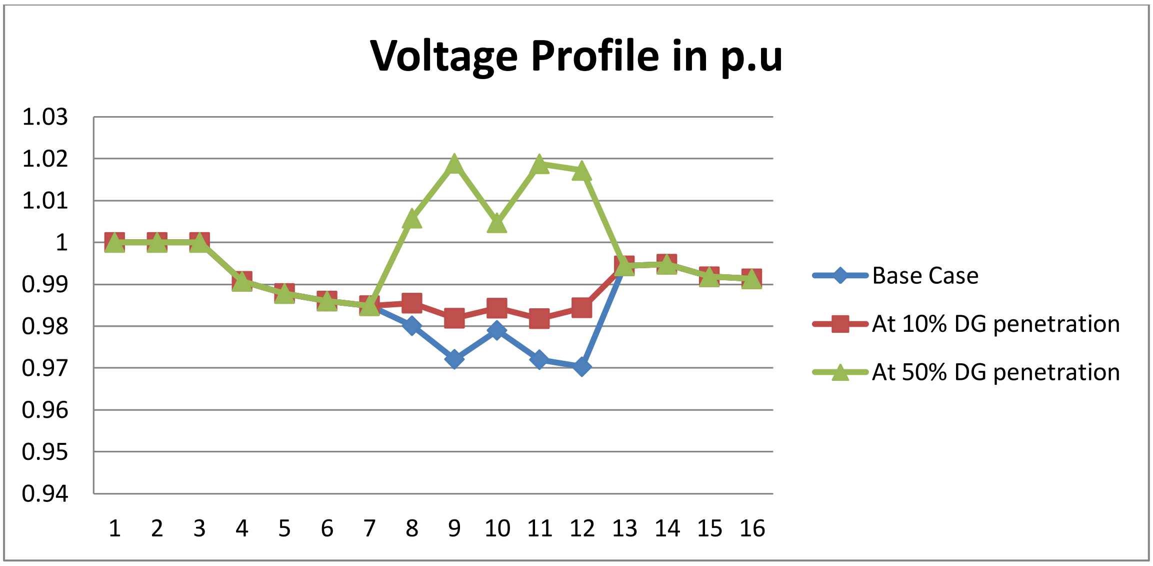

Figure 3 Voltage profile of 5 Standard Civanlar 16 bus Test system

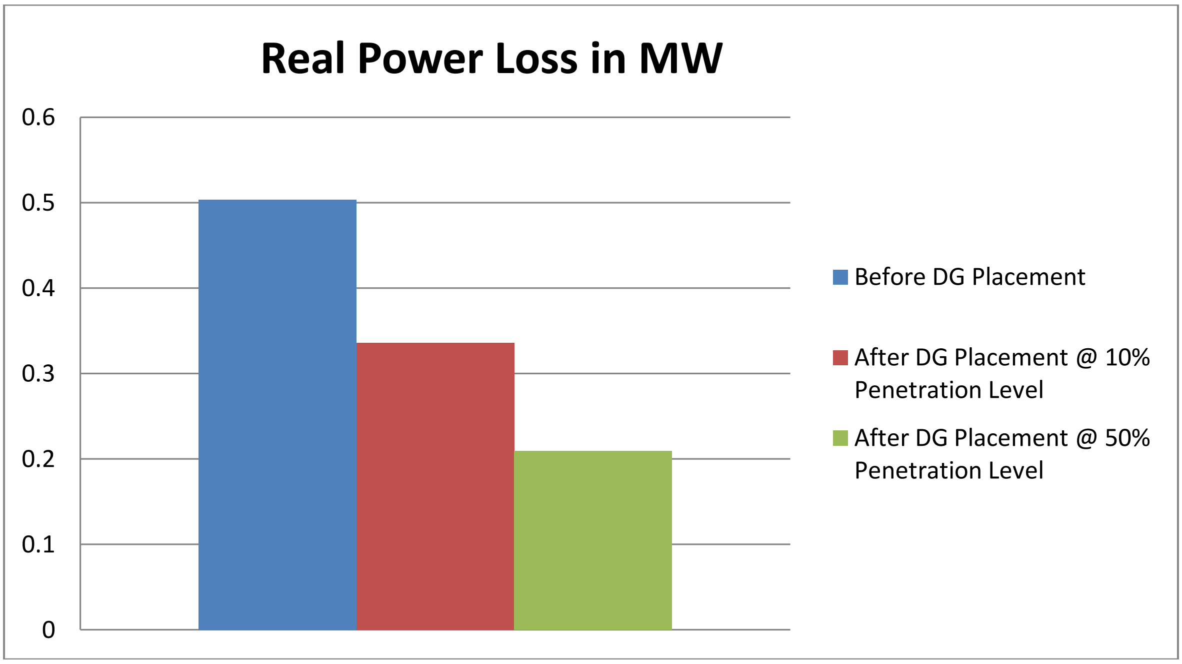

Figure 7 Real Power Loss profile of Standard 16 Bus Test System

6. CONCLUSION

Size and location of DG are crucial factors in the application of DG for loss minimization. This paper presents an algorithm to calculate the optimum size of DG at various buses and proposes a fast methodology to identify the best location corresponding to the optimum size for reducing total power losses in primary distribution network. The proposed methodology for location selection correctly identifies the best location for single DG placement in order to minimize the total power losses and improve the voltage profile through Static Security Analysis. In practice, the choice of the best site may not be always possible due to many constraints. However, the analysis here suggests that the losses arising from different placement varies greatly and hence this factor must be taken into consideration while determining appropriate location. The optimal size and location of DG are two

important factors for the planning and operation of modern electric power distribution systems. This paper presents a simplified index based approach for optimum location and allocation of DG in distribution system in which the optimal siting of DG is determined by Static Security Index for improving the voltage profiles and power loss reduction. The proposed method is tested on IEEE 6 bus and standard Civanlar 16 bus system and results were tabulated. The obtained location and size is the most optimum location and size in all of the possible optimum solutions because of analyzing all of the locations and sizes for each bus.

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